ANNIHILATIONS AT 2 TRILLION VOLTS

Fermilab now has the world's most powerful proton-antiproton collider

By DIETRICK E. THOMSEN

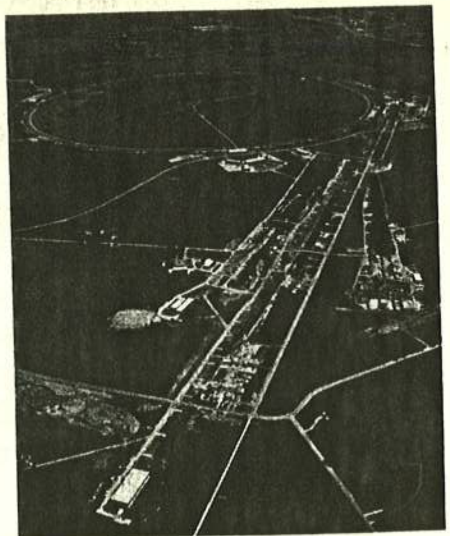
Two trillion electron-volts (2 TeV) equals the rest mass of somewhat more than 2,000 protons. This is the amount of energy that will ultimately be available from proton-antiproton collisions in the Tevatron at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Ill. Each colliding proton and antiproton will carry half the amount, more than 1,000 times its own rest energy. In the collisions, proton and antiproton will annihilate each other, forming a blob of pure energy, which will then transform itself into new phenomena. With such a huge amount of energy (by particle physics standards) available, physicists hope to see some of the very massive (again by particle physics standards) objects their theory leads them to expect, as well as entirely unpredicted phenomena.

At press time Fermilab physicists were preparing the final tests of a system that will make the Tevatron the world's most energetic proton-antiproton collider. Initially they expect to have a total energy of 1.6 TeV. This is three times the maximum energy available in such collisions in the proton-antiproton collider at the CERN laboratory in Geneva, formerly the world's most energetic and the only one operating up to now.

The Tevatron was already the world's most energetic accelerator of protons, and through half of this year it was operating in that mode, striking the protons against various fixed targets (instead of moving antiprotons) in a variety of experiments. This "fixed-target" physics is the other main way of doing particle physics experiments. Meanwhile the apparatus for making and controlling antiprotons and feeding them into the Tevatron was under construction with the intention of beginning colliding beam experiments sometime in 1986.

According to Fermilab's director, Leon Lederman, "Last April or May we realized that we could test the whole [antiproton] system, and decided to do it."

On earth, antiprotons are difficult to produce and extremely difficult to keep in any amount. Keeping them requires preventing them from touching ordinary matter, such as the walls of the vessel in which they are kept or stray gas atoms that may remain in even a very high vacuum chamber. The Fermilab apparatus is designed to accumulate 10^{11} antiprotons per hour.



Illustrations: Fermilab

Tevatron ring encloses a square mile.

At the moment the antiproton source is working at 10 percent of the design rate, 10^{10} antiprotons per hour. At CERN the rate of antiproton production is 5×10^9, says John Peoples of Fermilab, leader of the group working on the antiproton source. Therefore, he says, "10^{10} is still a very ambitious goal for people who do not have experience."

To make antiprotons, the physicists begin with protons accelerated to 120 billion electron-volts (120 GeV) and strike them against a solid target. Out of the target come both antiprotons and secondary protons. There are about five secondary protons to each antiproton. This circumstance led the team to use the secondary protons at first to test various components of the system. Protons are easier to handle, and they make an easy diagnostic tool, Peoples says. If the operators reverse the polarity of all the bending and focusing magnets, protons will go through the system in the direction intended for antiprotons. Bits of the system were tested separately and then put together. "It's like an oratorio," Peoples says. "First the singers practice alone, then comes the rehearsal when they all get together."

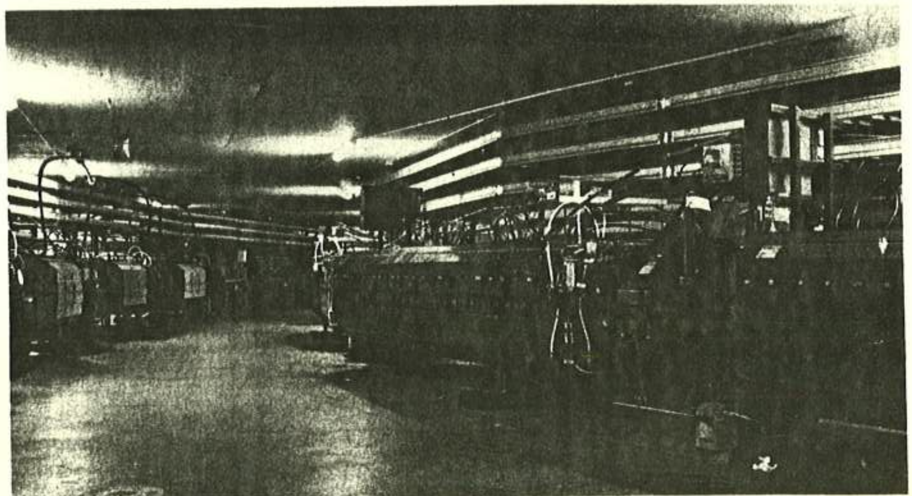
When all the components are together and working as designed, says Fred Mills, one of the physicists working on the antiproton source, the system will get about 50 million antiprotons per shot off the target. They come with a wide range of energies, moving in a wide spread of directions, and in bunches that reflect the pulse rate of the 120-GeV protons that made them. The system must now prepare the antiprotons for injection into the main accelerator. To do that it has to adjust their energies, momenta and timing.

First the antiprotons pass through a 15-centimeter-long magnetic lens made of lithium. This focuses them, bending their trajectories until they are more or less parallel to each other. The antiprotons then pass through two rings (which are shaped like triangles with rounded corners), the debuncher and the accumulator.

As Mills describes it, the debuncher works on their timing and the spread or variation in their momenta. It spreads the antiprotons out in time and shrinks the spread of their momenta. According to Peoples, they typically go in with about 3 percent variation of momenta and come out with about half a percent spread. This equalizing of momenta is known as cooling, and the antiprotons get more of it in the accumulator ring, which concentrates them laterally, narrowing the beam, and adjusts the spacing of their bunches, as it collects the number appropriate for injection into the main ring. It also brings their energy to 8 GeV to match that of the protons being prepared in the booster accelerator that has functioned as a proton preparer since Fermilab began experiments in 1972.

Because protons and antiprotons have opposite electric charges, they will move in opposite directions in the double main ring of the accelerator. Passage through both rings will bring the beams to 800 GeV each. By adjusting their trajectories with magnets, the researchers can make the protons and antiprotons collide at several points around the circumference of the Tevatron. Detectors are now being prepared for two of those points, known as B0 and D0. (The Tevatron is divided into six equal sectors, designated A through F.)

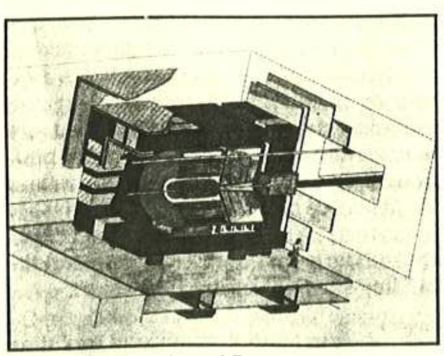
The detector for the B0 point, known as the Collider Detector Facility (CDF), is now almost ready for work. It was built in a large hall adjacent to the Tevatron and then was rolled into place so that it surrounds the point where the protons and antiprotons collide. If later an alternate detector is desired for this point, it can be assembled in the hall while the present one is working. The foundations for the hall at the D0 point have just been poured; the detector remains to be assembled.



The two rings that prepare antiprotons for injection into the Tevatron are shown here in a curving portion of their tunnel. Debuncher at right, accumulator at left.

The CDF is designed to detect anything and everything that may come out of proton-antiproton collisions. Physicists hope to see a wide variety of phenomena, both those predicted in the current "standard model" of theory and those that may go beyond the standard model into new territory. The CDF is so well prepared for anything that Roy Schwitters of Harvard University, one of the physicists associated with it, calls it a laboratory within a laboratory. It is that in the matter of personnel, too. The group that built it consists of almost 180 physicists from 13 U.S. institutions, two in Italy and two in Japan.

As Dennis Theriot of Fermilab describes it, the CDF covers all the space around the interaction point except the openings necessary to let the proton and antiproton beams through. At the center of the system is a time projection chamber that serves as a vertex detector. A vertex is a place where particle trajectories branch: Either a particle has struck something and knocked something out of it, or a particle has decayed radioactively. The idea is to detect vertices as close as possible to the collision point, as close ones may represent some of the very short-lived particles predicted by theory but not yet found. The central vertex detector is surrounded by a solenoid magnet. The magnetic field bends the trajectories of electrically charged particles, and the amount of curvature gives physicists a handle on the particles' identities, masses and energies. The central detector is surrounded by calorimeters, some designed for electromagnetic particles such as electrons and positrons and others for hadrons, the particles made of quarks, of which there are upward of 100.



Artist's conception of D0 detector. Barrel-shaped central vertex detector surrounds proton-antiproton collision point. Calorimeters surround vertex detector.

A calorimeter measures energy and momentum. It usually consists of slabs of a very dense material, inside which particles are likely to interact. In this case both lead and steel are used. Alternating with the slabs is a material in which the particles produced in the interaction can make tracks and something to detect the tracks. From a study of the tracks, physicists can determine the momentum and energy of the particle that interacted in the lead or steel. At the ends of the CDF, which is about 80 feet long and 36 feet in diameter, are muon calorimeters and series of magnetized steel toroids to detect muons that may be produced and sent off at angles very close to the path of the proton and antiproton beams.

Unlike the CDF, the detector at D0 will not have a central magnetic field, says Peter Kohler, one of the physicists working on it. The magnet is being left out to increase the hermeticity, the thoroughness of coverage. If a magnet had been included, there might have been cracks in the coverage through which particles might get away undetected.

The D0 is a true second-generation detector, Kohler says, having been designed in response to experience acquired at CERN. The work at CERN shows that proton-antiproton collisions at high energies tend to send out hadrons in jets, bunches confined in fairly narrow cones.

D0 is designed to study the jets and the electrons and muons that come out, as well as to pinpoint "missing" energy, which may represent unknown, unexpected and unrecorded particles. "What you need is a combination of some tracking and good calorimetry," says Kohler. The D0 will have a central tracking chamber — again to detect vertices close to the proton-antiproton collision point. Around this will be calorimeters made of slabs of uranium. Outside the calorimeter will be muon detectors. Muons are the most penetrating of electrically charged particles, and the detector is designed so that of charged particles only muons can get that far. The D0 detector is a collaboration of 100 physicists from 15 institutions in the United States and one in France. Completion is expected in 1989.

"We go in at three times CERN's energy," says Schwitters. "We expect a new threshold." They want to check the standard model. That includes studying the newly discovered W and Z particles, to find out, for example, what other kinds of particles are made with them and what particles they turn into. It involves looking for the Higgs particles, which play an important role in the standard model. It includes also a search for the top quark, the last outstanding of the six quark varieties. (CERN has a claim to discovery of the top, but Schwitters says discussion at a recent conference in Kyoto makes that out to be less certain than it seemed earlier.)

And then, he says, there is possible new physics, beyond the standard model. Some theorists had predicted a "desert" in this energy range, no new phenomena. Schwitters says this prediction was based on theories that require the proton to decay radioactively in about 10^{30} seconds. According to reports given at Kyoto from experimenters looking for proton decay, the proton doesn't decay in that time, so the possibility of new physics is a live one.

Also among these possibilities, according to Lederman, are the predictions of the so-called supersymmetry and technicolor theories, which predict a host of new particles, and the question of whether quarks have internal structure, which would mean that there is a still finer level of physical structure to look into. □